MOTIVATION

- SMBHs play a fundamental role in galaxy evolution.
- SMBHs affect their larger environment.
- Environment is inextricably linked to galaxy/SMBH evolution.
- AGN can also be a contaminant for ICM studies.

Aird et al. 2015
Silk & Mamon 2012
**MOTIVATION**

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\[
e_n(r/R_{500}) \propto E(z)^c
\]
MOTIVATION

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• AGN can also be a contaminant for ICM studies.

Mapping where SMBH live and their host galaxy properties can tell us about the conditions required to trigger them.
WHAT DO WE KNOW?

- X-ray AGN quenched in low-z clusters.
- Are X-ray AGN triggered at high-z?

WHAT DO WE KNOW?

Adapted from Krishnan et al. 2017

Benson et al.
WHAT DO WE KNOW?

Cluster X-ray AGN number densities have been shown to have some cluster mass dependence as have optical AGN.

See also Poggianti et al. 2006; Koulouridis et al. 2018…
WHAT DO WE KNOW?

- Consider mass, redshift, dynamical state

Adapted from Krishnan et al. 2017

Triggers [ whatever ]

Clusters (Martini+ 2009, 2013)

Proto-clusters
(Lehmer+ 2009, 2013,
Digby-North 2010
Krishnan+ 2017,
Macuga+ 2018)

\( f_{\text{AGN}} \propto (1 + z)^{5.3 \pm 2} \) vs \( f_{\text{SF}} \propto (1 + z)^{5.7 \pm 2} \)
Quantitatively how do AGN depend on host cluster and host galaxy properties?

**Challenging as:**

- Most massive clusters are best (easily characterized + large variation in ICM density) but lots of clusters would require a large area survey
- AGN and host galaxy properties are diverse
- AGN are rare in clusters yet abundant in background and spectroscopically identifying them is expensive
- For X-ray AGN cluster itself presents a challenging background
WHAT DO WE WANT TO KNOW?

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Our solutions:

• Use pointed observations in Chandra archive

• Multi-wavelength AGN selection and data for host galaxies

• Make differential measurements. Utilize knowledge of how large scale structure evolves to statistically combine signals.

• Requires high-spatial res X-ray obs. Developed metric to determine whether source on cluster background is point-like or extended
WHAT DO WE WANT TO KNOW?

Quantitatively how do AGN depend on host cluster and host galaxy properties?

**Challenging as:**

- For X-ray AGN cluster itself presents a challenging background
- For AGN are rare in clusters yet abundant in galaxies. In this region, we are most prone to spurious sources due to the rapidly varying background. We are also very sensitive to slight sub-pixel shifts in the centroiding precision, with a sigma of 10 pixels, after removal of bright AGN.

**Our solutions:**

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CATS - CLUSTER AGN TOPOGRAPHY SURVEY

- > 25 Ms of Chandra data (~500 clusters), VLA FIRST+ATCA, Spitzer+Wise, 293 orbit HST…

- ~40,000 X-ray AGN. ~11,000 radio AGN sources (~4,000 point sources, ~7000 extended)

- Differential analysis of superposition of cluster + field population. Cluster population is split into satellites and BCGs.

- ‘No evolution’ means ‘no evolution beyond that of the field’ population

Canning et al.; King et al.; Noordeh et al.
WHAT HAVE WE FOUND?

- I will present binned X-ray results but for the radio I will present the unbinned full model results
MASS AND REDSHIFT
MASS V'S REDSHIFT

Canning et al.

X-RAY AGN

\[ \text{Log}_{10} \left[ \frac{M_{500}}{M_{\odot}} \right] \]

\( z < 0.25 \)

\( 14 < \text{Log}_{10} M < 14.5 \)

Redshift, \( z_{\text{cl}} \)
X-RAY AGN

MASS V'S REDSHIFT

Noordeh et al.

\[ N \text{ deg}^{-2} (r < 2r_{500}) \]

\[ \log_{10} \left( \text{Cluster } M_{500}, M_\odot \right) \]

\[ F_x > 10^{14}, z < 0.25 \]

Canning et al.
X-RAY AGN

MASS VS REDSHIFT

Noordeh et al.

Canning et al.

Figure 6. Left: AGN fraction as a function of V-band magnitude limit (see section 2.2) and due to slit-packing (see section 2.6). While completeness both due to X-ray point source detection (see section 3.1) and inactive cluster member galaxies.

Population in fig. 7 with AGN shown as blue circles with area proportional to their X-ray luminosity. We find no evidence to their X-ray luminosity. We find no significant difference between active and inactive cluster member, both active and inactive, and plotted in fig. 7.

3.2 Local galaxy density

Cluster mass as black points with Poisson error bars. The black solid curve shows the best fitting model (fit to unbinned data) with the grey error bars. The black solid curve shows the best fitting model with the grey band highlighting the 1 uncertainty on the fit. The field AGN fraction is shown in dashed black. The inset shows the PDF of the mass dependence as described in section 3.1.

 图片 1

Figure 8. Left: The cluster AGN fraction is suppressed relative to the field in their overall sample, they did look at the X-ray AGN fraction in 167 poor/intermediate mass clusters, which scales as $n_{\text{AGN}} \propto M_\text{cl}^{0.2}$ and to an identically selected sample of field AGN from the CATS survey aims to answer the questions 1) does AGN activity depend on environment and if so 2) what drives this dependence. Our observations of seven massive galaxy clusters, which encloses the 10 nearest galaxies in projection with radius $r_{\text{proj}} = 7.74\,\text{Mpc}$, we computed the projected local galaxy density $n_g(r_{\text{proj}})$. This result is independent of the $cz$ dependence.

Noordeh et al. (2018) used $m_{\text{cl}} = 10^{15} \, M_\odot$ as the mass limit for their sample of clusters, which results in their fraction of AGN $F_{\text{AGN}} \approx 0.07$. While they found no suppression of cluster AGN activity when they selected for only the highest mass clusters in their sample. They also found that the cluster AGN number density on cluster mass, which is computed for every spectroscopically confirmed cluster, is proportional to their X-ray luminosity. We find no evidence of the cluster AGN number density on cluster mass, which scales as $n_{\text{AGN}} \propto M_\text{cl}^{0.2}$.
SO FAR… MASS DEPENDENCE… BUT

- No simple relation: Steepness of number density v's cluster mass relation is dependent on AGN flux.
- Codes now running which allow this flexibility.

X-RAY AGN

Canning et al.
However, there is also another strong jet (gas (Markevitch et al. 2000; Andrade-Santos et al. 2013). X-ray observations of Coma and Abell 2142 show evidence for surviving coherent substructures in the X-ray emission more likely to be relaxed (Mantz et al. 2015). Taken collectively, these substructures and have a strong radio jet (Interestingly, NGC 4874 is at the center of one of Coma’s disrupted clusters containing many smaller substructures and has a strong radio jet (Vijayaraghavan & Riley 2013). Those substructures may also retain their enhancement of satellite radio AGN (Vijayaraghavan & Riley 2013). Those substructures may also retain their enhancement of satellite radio AGN (Vijayaraghavan & Riley 2013)).

The calculations made by Mamon (1992, 2000) assume a range of dynamical cluster states from relaxed to highly collisional, redshift, peakiness, and cluster mass dependencies. We fit the two-point correlation function.

In a well defined sample of 174 clusters. In the satellites, they can not precisely locate these grouped components, account for the multiple components in their sample, to fit the two-point correlation function.

Approximately 10–30% of sources are thought to be divided into multiple components in the FIRST survey (Cress et al. 1996; Overzier et al. 2003; Lindsay et al. 2014). This particular radial extent of FR II jets and cosmic evolution of radio-mode AGN in clusters.

Various studies have shown that the location of a BCG at the center of a relaxed cluster potential (and the associated enhanced magnetic activity may substantially impact SZE.

Weak evidence for Satellite mass dependence. No BCG mass dependence.

Weak evidence for BCG evolution. No Satellite evolution.

King et al.
DYNAMICAL STATE
Cluster dynamical state

Cluster morphology Symmetry-Peakiness-Alignment see Mantz et al. 2015
CLUSTER DYNAMICAL STATE

(a) Relaxed Clusters

(c) Least Relaxed Clusters

Canning et al.
Cluster Dynamical State

Cluster morphology Symmetry-Peakiness-Alignment see Mantz et al. 2015

Canning et al.

X-RAY AGN
WHAT’S NEXT?

• Full dataset for X-ray, radio and IR AGN.

• Comparison with galaxy population distributions particularly star formation.

• Comparison to models of merger rates and environmental processes in clusters.
WHAT’S NEXT?

• eROSITA: superb understanding of low-z halo mass dependence

• Athena: great statistics on higher redshift (z~1) AGN in clusters

• Lynx: AGN at the epoch of cluster formation
WHAT'S NEXT?

2 keV, $z = 3$ cluster + AGN ($5 \times 10^{-17}$ erg/cm$^2$/s)